13.—Concentrations of major nutrient elements in vegetation and soils from a portion of the Western Australian arid zone

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Manuscript received 22 October, 1968; accepted 18 March, 1969.

Abstract

Soil and plant samples from twenty-two sites representative of six ecological units were collected from central Western Australia where rainfall averages less than 10 inches (25.4 cm) per annum. Most soils are acid in reaction and have low levels of phosphorus and potassium as well as low cation exchange capacities. Only in limited areas are soils high in carbonate or soluble salts.

Concentrations of nitrogen and phosphorus, and nitrogen and sulphur were highly correlated. In the case of *Acacia aneura*, which was present on most sites, it was possible to illustrate a significant correlation between soil and foliar concentrations of phosphorus. *Acacia salicina* was found to have unusually high amounts of sulphur and calcium, and this was due to the presence of calcium sulphate apparently mainly on the external surface of the leaves.

Chenopods growing in saline environments have high concentrations of the cations sodium, potassium, calcium, and magnesium. *Salsola kali* and *Rhagodia gaudichaudiana* are distinguished from other chenopods by high contents of potassium relative to sodium.

Introduction

In 1965 the authors traversed central Western Australia on a route extending from Kalgoorlie, via Laverton and the Warburton Mission, to Giles, and returning to Mount Magnet via Carnegie Station, Wiluna and Meekatharra (Fig. 1). This area, for the greater part, lies outside the inhabited portion of the state and is thus little known and rarely visited. Consequently the opportunity was taken to collect samples of soils and plants from several soil-plant communities or ecosystems. Samples were later analysed to determine the concentration of the major elements in both foliage and soils, so that possible relationships between these could be studied.

Environment

Soil and vegetation samples were largely collected from the Gibson Desert, but some were taken from the pastoral districts which adjoins to the west (Fig. 1). The study area lies wholly within the Eremean botanical province, and includes parts of the mulga bush formation, *Triodia* steppe, and desert (Gardner 1942). A more detailed description of vegetation in the western portion has been given by Speck (see Mabbutt *et al*, 1963), while similar sand dune vegetations have been described by Eardley (1946, 1949) for the Simpson Desert in central Australia.

Climatic data are recorded at a number of stations within the area (Anon 1956, and Commonwealth Bureau of Meteorology unpublished data). In all cases annual average rainfall (Fig. 2) is less than 10 inches (25.4 cm), and ranges from 24 cm at Wiluna to 18 cm at Giles. Temperatures reach an average maximum of approximately 100°F (38°C) during December, January, February, and March, and an average minimum of about 40°F (4.5°C) during June, July, and August. As a result of the low and irregular rainfall, and extreme heat, perennial vegetation is almost entirely restricted to species able to survive for several years on rain insufficient to permit growth.

The area is a gently undulating plateau with elevations ranging from 400 metres to 525 metres, and with occasional stony ranges to 675 metres. Correlation between topography, vegetation, and soils is marked, and the following six broad ecological units may be recognised. Most extensive are broad *mulga plains* which have shallow soils commonly overlying siliceous hardpan (Teakle 1936, Mabbutt *et al*, 1963). There is normally a surface pavement composed of the more resistant of the country rocks, but this thins out towards the drainage lines where there is a general increase in the depth of soil cover. Slightly elevated above the mulga plains, and in places separated by small erosional scarps or breakaways, are *spinifex uplands* where soils are shallow and gravelly, and overlie duricrust formed from lateritic mottled zones. Ferricrete and silcrete are frequently exposed in the breakaways. Extensive dune fields, the *spinifex sandhills*, occur in the Gibson Desert area. They are largely associated with broad flats, and seldom extend onto the gravelly uplands. Where water relations are better than average, as on sandy outwash plains at the foot of rocky ranges, and on some of the less saline drainage lines, there are *Casuarina* flats. Elsewhere the main drainage lines, which are marked by strings of playa lakes and evaporate deposits, have *saltbush flats* on the more saline sections, and *eucalypt flats* on shallow calcareous soils overlying kankar.

Description of sample sites

Twenty-two sites representative of the six ecological units were sampled and are described in more detail below. At each site foliage of all prominent plants was collected, and the soil profile was sampled at depths of 0 to 3 inches (0-7.5 cm), 3 to 6 inches (7.5-15 cm), and 6 to

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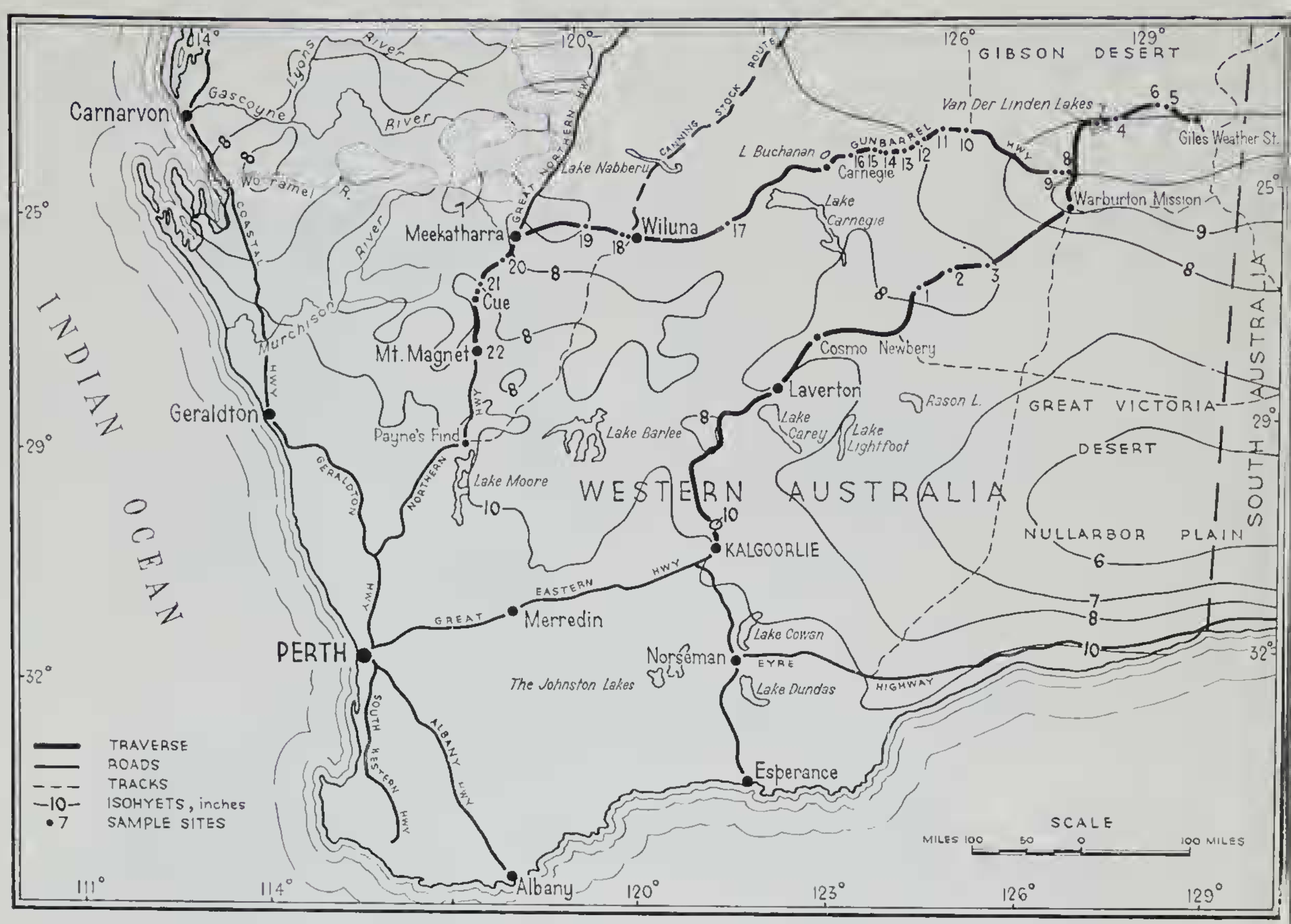

Figure 1.—Locality plan and traverse map showing isohyets of average annual rainfall in inches.

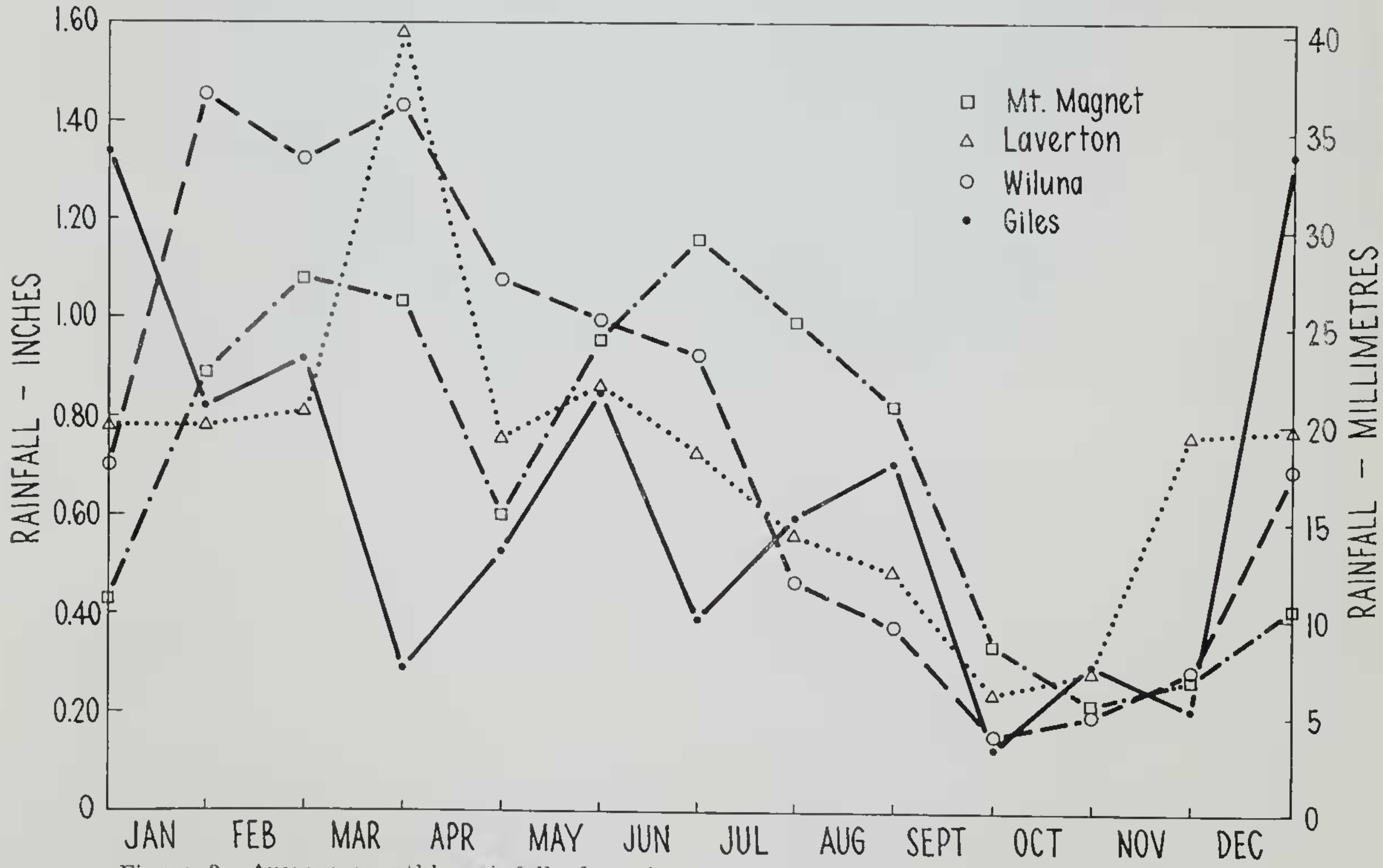

Figure 2.—Average monthly rainfalls for selected sites in the Western Australian arid zone.

12 inches (15-30.5 cm). Soils are described in terms of the keyed classification of Northcote (1965).

(1) *Mulga plains* (Sites 1, 2, 9, 12, 14, 19, 21): This unit (Fig. 5) is most extensive particularly in the pastoral districts, and is also found on erosion plains throughout the study area.

Soils range from red coherent sands (Uc1.43), and earthy sands with a slight increase in clay content at depth (Uc5.21), to red earthy loams (Um5.3), and neutral red earthy soils with a gradational increase in clay plus silt content with depth (Gn2.12). All overlie acid hardpan which is seldom greater than 40 inches and often less than 6 inches from the surface.

Vegetation is dominated by a tree cover of mulga (*Acacia aneura*) and other *Acacia* species, with occasional *Eucalyptus youngiana* and *Canthium latifolium*, often occurring in distinct bands, together with the shrubs *Eremophila latrobei* and spp, *Santalum lanceolatum*, *Cassia sturtii*, and *Ptilotus obovatus*. There is a variable ground cover of the grasses *Triodia pungens*, *T. basedowii*, and *Danthonia bipartita*.

(2) *Spinifex uplands* (Sites 8, 10, 11): This unit (Fig. 6) is extensive on Gunbarrel Highway between Fame Range and the Van der Linden Lakes, but also occurs in smaller patches elsewhere.

Soils show little variability, being red earthy sands, and sandy loams, which have a slightly higher clay content at depth; the whole profile is dominated by the gravel fraction (KS Uc5.21)*.

There is a continuous, though patchy cover of spinifex (*Triodia basedowii*), and scattered, stunted trees of mulga and gidgee (*Acacia pruinocarpa*), with *Hakea lorea*, *Anthobolus exocarpoides*, and mallee (*Eucalyptus kingsmillii*).

(3) *Spinifex sandhills* (Sites 3, 4, 15, 16): These (Fig. 7) largely occur below the spinifex uplands and are particularly extensive east of Lake Buchanan and Cosmo Newberry.

Dunes are composed of acid, red, loose sands (Uc1.23), while the soils of interdune corridors are more coherent with an earthy fabric and a slight increase in clay content at depth (Uc5.21).

Dune vegetation consists of scattered small trees of mulga and other *Acacia* species—particularly *A. salicina*, which is frequently parasitised by *Loranthus exocarpi*,—mallee (*Eucalyptus ewartiana* and spp), *Gyrostemon ramulosus*, *Grevillea stenobotrya*, and *Hakea rhombalis*. There is a low shrub cover of *Thryptomene maisonneuvii*, often occurring in dense thickets with *Helipterum adpressum*, *Crotalaria cunninghamii* and *Dicrastylis* sp. The grasses *Triodia pungens* and *Aristida nitidula* form a groundcover.

* The prefix KS here refers to gravels mainly composed of iron and aluminium oxides, which were probably formed in these soils by the breakdown of indurated mottled zone materials which commonly occur within 12 inches of the surface.

(4) *Casuarina flats* (Sites 5, 6, 7): These (Fig. 8) occur largely in the east of the area near some of the less saline drainage lines, and at the foot of rocky ranges where water relations are probably better than average.

Texturally soils are similar to those of the spinifex sandhills, being red loose sands (Uc1.23); but they are frequently alkaline at depth where drainage is impeded and there are associated kopi gypsum deposits.

Vegetation is dominated by large trees of desert oak (*Casuarina decaisneana*), with scattered *Acacia* spp—particularly *A. salicina*—mallee (*Eucalyptus gamophylla*), and quondong *Santalum acuminatum*). There is sparse shrub cover of *Eremophila* spp. *Cassia sturtii*, and *Thryptomene maisonneuvii*, together with *Alyogyne pinonianus*, *Ptilotus obovatus*, and *Dodonaea attenuata*, and the grasses *Triodia pungens*, *T. basedowii*, *Eragrostis* sp., and *Amphipogon strictus*.

(5) *Saltbush flats* (Sites 13, 17, 20, 22): These occur largely in sump situations representing former drainage lines, but are occasionally found on moderate slopes where seepage occurs.

Soils are rather variable, but are largely non-calcareous red sands (Uc1.23 and Uc1.43). Occasionally there are sands overlying acid hardpan at shallow depths (Uc5.13), and less often red soils with gradational texture profiles in which calcium carbonate is clearly visible throughout the solum (Gc1.22).

Vegetation is confined almost entirely to herbaceous shrubs and annuals of the chenopod family including saltbush (*Artriplex hymenotheca*, *A. inflata*, and *Rhagodia gaudichaudiana*), blue bush (*Kochia carnosa*, *K. pyramidata*), bindy-eye (*Bassia drummondii*, *B. gardneri*, *B. paradoxa*, *B. obliquicuspis*), and roly-poly (*Salsola kali*). On fringing areas and less saline ridges there is a variable cover of trees (*Acacia* spp, and *Hakea* sp.), and the shrubs *Cassia sturtii*, *Eremophila* spp, *Lycium australe*, *Hemichroa diandra*, and *Plagianthus* sp.

(6) *Eucalypt flats* (Site 18): This unit occurs largely in the upper sections of the saline drainage lines. It appears to be more common in the area where drainage is to the west coast, and here forms part of the Cunyu and Mileura land systems (Mabbutt *et al.* 1963).

Soils are typically loams in which there are large amounts of calcareous rubble (kankar) and a lime pan at shallow depth (Um5.11).

Characteristically vegetation consists of large trees of river gum (*Eucalyptus camaldulensis*), with scattered mulga, *Pittosporum phillyraeoides* and *Santalum lanceolatum*. There is a variety of shrubs and annuals including *Eremophila longifolia*, *Solanum lasiophyllum*, *Zygophyllum*, sp., *Cephalipterum* sp., and *Indigofera brevidens*.

Results

A complete list of plant species at each site, together with results of laboratory analysis of soil and foliage samples has been presented by

TABLE 1

Means and ranges of properties of soils from mulga plains
(Sites 1, 2, 9, 12, 14, 19, 21)

	Saturation extract					Exchangeable cations (m.e./100 g)				HCl soluble		
	% H_2O at saturation	Ec millimhos/cm at 20° C	pH sat. extract	pH 1:2½ M/100	C.E.C. m.e./100 g KCl	Na	K	Ca	Mg	% P	% K	% Na
0–3″	20 (17–24)	0·19 (0·09–0·26)	5·7 (4·4–7·3)	4·6 (3·8–6·2)	3·3 (2·1–5·6)	0·08 (0·01–0·20)	0·31 (0·1–0·65)	0·80 (0·05–1·6)	0·30 (0·05–1·1)	0·020 (0·006–0·042)	0·047 (0·030–0·087)	0·016 (0·006–0·033)
3–6″	20 (15–25)	0·26 (0·12–0·46)	5·1 (4·2–6·4)	4·3 (3·8–5·0)	3·3 (2·3–5·9)	0·08 (0·01–0·27)	0·25 (0·12–0·56)	0·91 (0·05–1·4)	0·30 (0·05–1·4)	0·018 (0·005–0·035)	0·045 (0·027–0·075)	0·017 (0·009–0·036)
6–12″	20 (16–25)	0·37 (0·10–0·91)	5·1 (4·2–6·1)	4·4 (3·8–5·4)	3·2 (2·4–6·1)	0·09 (0·01–0·34)	0·24 (0·14–0·48)	0·88 (0·05–1·8)	0·29 (0·05–1·0)	0·017 (0·005–0·032)	0·049 (0·025–0·085)	0·017 (0·009–0·041)

TABLE 2

Means and ranges of properties of soils from upland gravel plains
(Sites 8, 10, 11)

	Saturation extract					Exchangeable cations (m.e./100 g)				HCl soluble		
	% H_2O at saturation	Ec millimhos/cm at 20° C	pH sat. extract	pH 1:2½ M/100	C.E.C. m.e./100 g KCl	Na	K	Ca	Mg	% P	% K	% Na
0–3″	19 (17–20)	0·12 (0·11–0·16)	5·4 (4·9–5·8)	4·2 (4·1–4·3)	2·4 (2·0–2·6)	0·05 (0·01–0·11)	0·10 (0·08–0·12)	0·35 (0·15–0·6)	0·15 (0·15–0·15)	0·012 (0·009–0·013)	0·023 (0·020–0·026)	0·012 (0·012–0·013)
3–6″	20 (19–20)	0·16 (0·13–0·20)	5·2 (4·4–6·1)	4·2 (4·2–4·2)	2·4 (2·0–2·7)	0·01 (0·01–0·02)	0·13 (0·10–0·14)	0·38 (0·15–0·5)	0·17 (0·15–0·2)	0·011 (0·009–0·012)	0·025 (0·020–0·031)	0·013 (0·012–0·014)
6–12″	19 (19–20)	0·19 (0·13–0·30)	5·3 (4·8–5·9)	4·4 (4·3–4·6)	2·6 (2·2–3·2)	0·04 (0·04–0·04)	0·16 (0·13–0·19)	0·62 (0·2–1·25)	0·23 (0·15–0·2)	0·011 (0·009–0·010)	0·028 (0·023–0·037)	0·014 (0·013–0·015)

Keay and Bettenay*. They are further discussed below in order of soil-plant communities described in the previous section.

a. *Soil properties*

(1) *Mulga plains*.—These soils are characteristically acid, with about half of the exchange capacity saturated with bases (Table 1). Concentrations of acid-soluble phosphorus are low, and the mean values for chemical properties show little variation with depth.

(2) *Spinifex uplands*.—The high content of gravel (>2mm fraction) further dilutes the very low concentrations of plant nutrient which are expressed in Table 2 in terms of the fraction <2mm. The matrix is acidic with only about one third of the exchange capacity occupied by bases. Chemical properties are uniform within the top twelve inches.

* C.S.I.R.O. Division of Soils, Adelaide, Tech. Mem. 18/67 available on request.

(3) *Spinifex sandhills*.—These soils have the lowest cation exchange capacities and acid-soluble phosphorus concentrations of all soils examined (Table 3). The highest concentration of acid-soluble phosphorus is 50 ppm. and assuming 10^6 lb soil/acre—3 inches, represents only 50 lb P/acre.

Although the soils are acidic, the exchange complex is almost saturated with bases, the dominant cations being calcium and magnesium. The measurement of such small quantities of exchangeable cations etc. involves relatively large laboratory error, but the values for pH, cation exchange capacity and acid-soluble phosphorus and potassium cover a narrow range of values, and do not vary with depth.

(4) *Casuarina flats*.—Chemically these soils are similar to sandhill soils, but have higher concentrations of acid-soluble phosphorus and potassium (Table 4). The pH and cation ex-

change capacity values are also higher than in the dune soils.

(5) *Saltbush flats.*—The soils of this unit are characteristically saline (Table 5) although some surface soils are not high in soluble salts. Soils are neutral in reaction, with about 40% of the exchange complex occupied by bases. Levels of acid-soluble phosphorus, potassium, and sodium are higher than in most soils examined.

TABLE 3

Means and ranges of properties of soils from spinifex sandhills
(*Sites* 3, 4, 16)

	Saturation extract					Exchangeable cations (m.e./100 g)				HCl soluble		
	% H_2O at saturation	Ec millimhos/cm at 20° C	pH sat. extract	pH 1:2½ M/100	C.E.C. m.e./100 g KCl	Na	K	Ca	Mg	% P	% K	% Na
0–3″	21 (20–22)	0·23 (0·094–0·49)	5·9 (5·3–6·5)	5·7 (5·3–6·0)	0·87 (0·8–1·0)	0·03 (0·01–0·04)	0·05 (0·04–0·06)	0·27 (0·2–0·3)	0·13 (0·1–0·2)	0·0033 (0·0024–0·0044)	0·007 (0·005–0·01)	0·003 (0·001–0·004)
3–6″	22 (21–22)	0·20 (0·06–0·42)	5·8 (5·3–6·2)	5·6 (5·0–5·2)	0·80 (0·5–1·4)	0·06 (0·02–0·12)	0·037 (0·04–0·07)	0·35 (0·2–0·45)	0·10 (0·1–0·1)	0·0034 (0·0023–0·0048)	0·008 (0·005–0·013)	0·003 (0·001–0·004)
6–12″	20 (19–20)	0·22 (0·06–0·49)	5·9 (5·5–6·2)	5·1 (4·9–5·2)	0·53 (0·2–0·9)	0·04 (0·01–0·08)	0·033 (0·04–0·07)	0·20 (0·1–0·3)	0·10 (0·1–0·1)	0·0030 (0·0023–0·0041)	0·007 (0·005–0·012)	0·003 (0·001–0·004)

TABLE 4

Means and ranges of properties of soils from Casuarina flats
(*Sites* 5, 6, 7)

	Saturation extract					Exchangeable cations (m.e./100 g)				HCl soluble		
	% H_2O at saturation	Ec millimhos/cm at 20° C	pH sat. extract	pH 1:2½ M/100	C.E.C. m.e./100 g KCl	Na	K	Ca	Mg	% P	% K	% Na
0–3″	16 (14–17)	0·20 (0·12–0·29)	7·0 (6·2–7·3)	6·0 (5·0–7·1)	1·7 (0·9–2·3)	0·07 (0·04–0·08)	0·14 (0·05–0·25)	1·22 (0·4–2·0)	0·27 (0·1–0·4)	0·0052 (0·0043–0·0069)	0·030 (0·017–0·037)	0·004 (0·003–0·005)
3–6″	16 (15–17)	0·25 (0·16–0·35)	6·7 (5·5–7·8)	6·1 (4·7–7·5)	1·8 (1·2–2·4)	0·08 (0·04–0·12)	0·15 (0·06–0·26)	1·25 (0·3–2·35)	0·27 (0·15–0·4)	0·0045 (0·0038–0·0056)	0·031 (0·020–0·037)	0·005 (0·004–0·005)
6–12″	16 (16–16)	0·22 (0·12–0·35)	6·1 (5·1–7·9)	6·1 (4·6–7·7)	1·8 (1·1–2·5)	0·05 (0·04–0·08)	0·16 (0·10–0·24)	1·30 (0·3–2·5)	0·20 (0·1–0·3)	0·0042 (0·0036–0·0051)	0·032 (0·020–0·041)	0·005 (0·004–0·006)

TABLE 5

Means and ranges of properties of soils from saline areas
(*Sites* 13, 17, 20, 22)

	Saturation extract					Exchangeable cations (m.e./100 g)				HCl soluble		
	% H_2O at saturation	Ec millimhos/cm at 20° C	pH sat. extract	pH 1:2½ M/100	C.E.C. m.e./100 g KCl	Na	K	Ca	Mg	% P	% K	% Na
0–3″	18 (13–21)	1·24 (0·14–2·05)	7·1 (6·1–8·0)	6·7 (5·5–7·8)	6·3 (1·1–11·1)	0·54 (0·02–1·3)	0·64 (0·19–1·44)	0·93 (0·5–1·5)	0·28 (0·1–·04)	0·015 (0·013–0·017)	0·13 (0·03–0·25)	0·04 (0·008–0·093)
3–6″	21 (16–24)	2·30 (0·11–4·90)	7·1 (6·0–8·1)	7·0 (5·7–8·4)	6·7 (0·8–13·3)	0·18 (0·02–0·3)	0·69 (0·2–0·25)	0·75 (0·7–0·8)	0·35 (0·3–0·4)	0·016 (0·013–0·023)	0·22 (0·03–0·61)	0·09 (0·008–0·26)
6–12″	25 (16–36)	4·56 (0·14–8·06)	7·3 (6·3–8·2)	7·2 (5·8–8·2)	4·5 (0·9–11·2)	0·51 (0·02–1·0)	0·25 (0·24–0·26)	0·80 (0·7–0·9)	0·40 (0·35–0·45)	0·014 (0·010–0·020)	0·20 (0·04–0·53)	0·14 (0·008–0·33)

TABLE 6

Properties of the soil from a eucalypt flat
(Site 18)

	SATURATION EXTRACT					EXCHANGEABLE CATIONS (m.e./100 g)				HCl SOLUBLE		
	% H_2O at saturation	Ec millimhos cm at 20° C	pH sat. extract	pH 1:2½ M/100 KCl	C.E.C. m.e./100 g	Na	K	Ca	Mg	% P	% K	% Na
0–3"	34	0·49	8·1	7·8						0·022	0·39	0·041
3–6"	43	0·32	8·3	7·9						0·018	0·43	0·041
6–12"	49	0·28	8·2	7·9						0·017	0·39	0·045

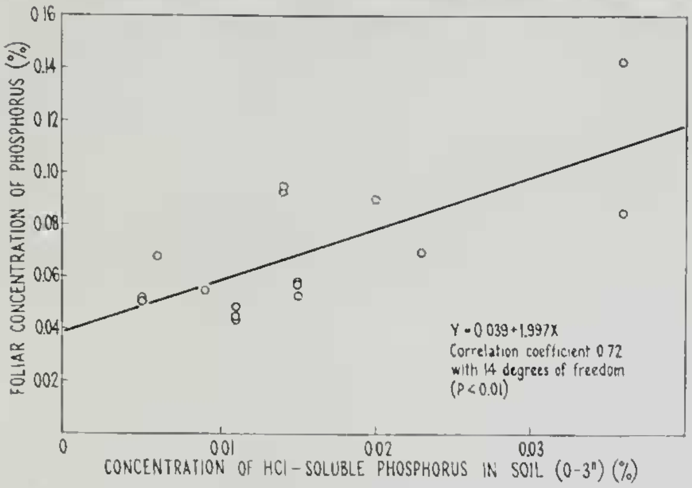

Figure 3.—The relationship between soil and foliar phosphorus concentrations in *Acacia aneura*.

(6) *Eucalypt flats.*—Only one site was examined, and the chemical properties of the soil are given in Table 6. It is alkaline in reaction, and has higher concentrations of acid-soluble phosphorus and potassium than all other soils.

b. *Foliar concentrations of nutrients*

The mean concentrations of each nutrient in the species sampled are given in Table 7. The number of samples for each mean is given in parenthesis.

Nitrogen concentrations are generally low, the grasses having the lowest values and the halophytes the highest. Nitrogen fixing species have concentrations between 1% and 2% in their dried foliage. Concentrations of phosphorus are low in almost all species, while potassium concentrations vary between wide limits, being lowest in the grasses and very high in a few specific plants notably *Rhagodia gaudichaudiana*, *Salsola kali* and *Calandrinia balonensis*. Sodium concentrations are generally low except in the halophytes, in which values are as high as 11% of the dried foliage. The concentrations of calcium vary widely with the grasses again having the lowest concentrations; occasionally a high concentration of calcium is accompanied by a high concentration of sulphur. Magnesium concentrations show a tendency to vary in the same way as calcium concentrations, although the values are generally lower. An exception is *Atriplex inflata* which has a higher concentration of magnesium than calcium. Sulphur concentrations are generally higher than those of phosphorus, with

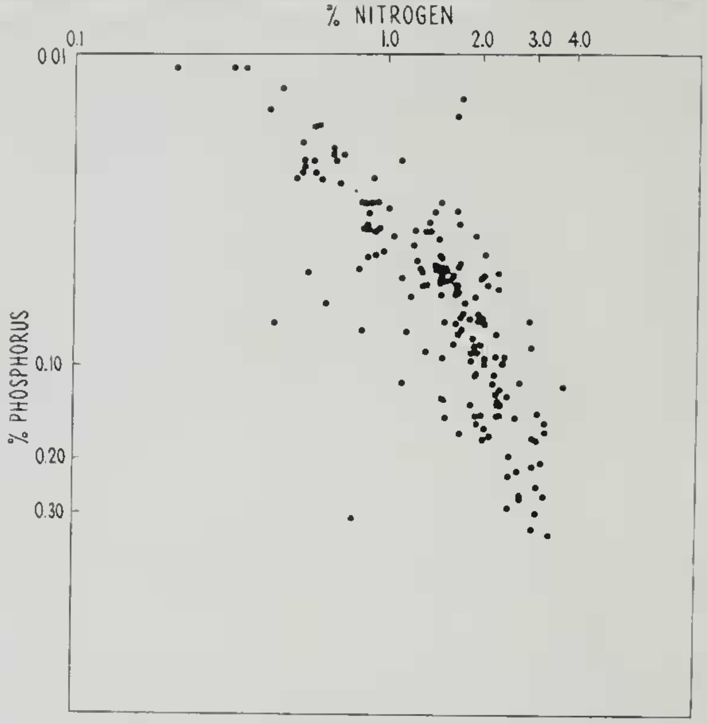

Figure 4.—The relationship between nitrogen and phosphorus concentrations in the foliage of all species.

occasional very high values, notably in *Acacia salicina and Gyrostemon ramulosus*. This is further discussed below.

Discussion

The soils at all sites, in common with most other Australian soils, have low or very low levels of phosphorus. Wild (1958) has attributed this to loss of phosphorus by weathering. Beadle (1962) considers it to be in many cases the result of the low concentrations of phosphorus in the rocks from which soils are derived. It seems probable that both are factors in the low content of phosphorus in these soils.

Acacia aneura occurred on several sites, and there was a significant correlation ($P<0.01$) between the concentration of phosphorus in the foliage and the soil phosphorus extracted by hot 5N HCl (Figure 3). The relationship between the nitrogen and phosphorus concentrations in the foliage of all species after logarithmic transformations is shown in Figure 4. The concentrations of the two elements are highly correlated ($r = 0.784$ with 125 degrees of freedom, $P<0.001$). Nitrogen and sulphur concentrations are also correlated, but to a lesser degree ($r = 0.484$ with 125 degrees of freedom, $P<0.001$).

One species, *Acacia salicina,* has unusually high concentrations of sulphur in its foliage, and since this is accompanied by similar high concentrations of calcium the foliage was tested for water soluble calcium sulphate. The presence of calcium sulphate was confirmed by shaking the ground leaf material with water for a few seconds and testing the extract with acetone. Microscopic examination* failed to detect crystalline gypsum in the tissues, and the calcium sulphate appeared to be concentrated on the external surface of the foliage. The possibility of a wind-blown deposit is considered unlikely since some of the sites were not near soils containing gypsum, and other species from

* We are indebted to Professor B. J. Grieve of the Department of Botany, Western Australian University, for this examination.

TABLE 7

The mean concentrations of nutrients in the species sampled

Species	No. of Samples	% N	% P	% K	% Na	% Ca	% Mg	% S
Aristida nitidula	(4)	0.40	0.015	0.23	0.02	0.33	0.06	0.08
Eragrostis sp.	(2)	0.60	0.024	0.31	0.01	0.24	0.09	0.08
Triodia basedowii	(8)	0.55	0.017	0.31	0.04	0.36	0.07	0.08
T. pungens	(5)	0.80	0.025	0.44	0.05	0.26	0.07	0.07
Danthonia bipartita	(1)	2.7	0.12	1.3	0.02	0.57	0.26	0.22
Casuarina decaisneana	(4)	1.1	0.033	0.83	0.04	1.2	0.18	0.11
Grevillea stenobotrya	(1)	0.7	0.022	0.45	0.06	6.2	0.22	0.20
Anthobolus exocarpoides	(2)	1.9	0.018	1.9	0.10	1.5	0.36	0.28
Hakea lorea	(2)	0.80	0.027	0.85	0.01	0.56	0.18	0.20
H. rhombalis	(1)	0.60	0.022	0.36	0.12	0.59	0.14	0.15
H. arida	(1)	0.80	0.031	0.75	2.5	1.9	0.13	1.0
Santalum lanceolatum	(2)	2.1	0.082	1.1	0.05	1.7	0.32	0·58
S. acuminatum	(1)	1.0	0.031	0.94	0.57	5.3	0.46	0.27
Rhagodia gaudichaudiana	(1)	3.2	0.20	10.2	4.0	1.5	0.94	0.29
Atriplex hymenotheca	(3)	2.0	0.14	2.8	7.0	1.5	0.78	0.46
*A. inflata**	(2)	3.1	0.28	3.2	5.9	1.4	2.1	0.29
Bassia drummondii	(1)	1.9	0.086	1.5	7.1	1.1	0.35	0.19
B. gardneri	(1)	1.9	0.11	2.0	8.9	1.6	0.39	0.23
B. paradoxa	(1)	1.8	0.13	2.2	3.8	0.87	0.36	0.24
B. obliquicuspis	(1)	1.9	0.14	2.4	2.4	1.5	0.43	0.18
B. sp.	(1)	2.2	0.13	2.0	5.6	1.1	0.34	0.20
Salsola kali	(2)	2.6	0.12	8.9	1.7	2.2	1.2	0.16
Kochia pyramidata	(2)	2.8	0.13	2.5	8.7	1.0	0.82	0.24
K. carnosa	(2)	2.3	0.14	2.4	5.4	0.60	1.2	0.25
K. sp.	(3)	2.0	0.085	3.0	11.0	0.82	0.58	0.31
Hemichroa diandra	(1)	1.9	0.090	2.6	3.8	3.7	2.7	1.0
Ptilotus obovatus	(4)	2.1	0.069	3.0	0.03	1.9	1.6	0.16
Gyrostemon ramulosus	(1)	3.6	0.12	1.3	0.28	4.5	0.77	1.8
Calandrinia balonensis	(1)	2.1	0.051	8.6	0.02	0.67	1.9	0.17
Pittosporum phillyraeoides	(1)	1.2	0.11	2.7	0.04	1.5	0.42	0.18
Acacia aneura	(16)	1.7	0.067	0.79	0.02	1.3	0.19	0.11
A. salicina	(7)	1.5	0.043	0.80	0.05	5.7	0.52	2.4
A. dictyophleba	(2)	1.4	0.045	0.69	0.01	0.51	0.19	0.09
A. kempeana	(1)	1.7	0.052	0.92	0.02	1.1	0.20	0.12
A. helmsiana	(1)	1.5	0.030	0.59	0.21	0.98	0.32	0.09
A. sibirica	(1)	1.4	0.035	0.81	0.02	1.4	0.20	0.08
A. tetragonophylla	(2)	1.5	0.054	0.83	0.03	0.80	0.28	0.09
A. exocarpoides	(1)	1.2	0.077	0.82	0.13	0.70	0.21	0.40
A. pruinocarpa	(4)	1.9	0.054	0.77	0.02	1.4	0.55	0.13
A. sp.	(1)	1.6	0.04	0.66	0.02	1.0	0.19	0.13
Cassia sturtii	(3)	2.1	0.11	0.98	0.07	1.6	0.21	0.16
Crotalaria cunninghamii	(1)	2.9	0.087	0.68	0.02	0.57	0.31	0.23
Indigofera brevidens	(1)	2.4	0.12	0.97	0.04	5.3	0.53	0.16
Zygophyllum sp.	(1)	3.3	0.15	2.7	0.06	9.8	0.74	0.55
Dodonaea attenuata	(2)	1.8	0.079	1.6	0.01	0.69	0.27	0.18
Alyogyne pinoniana	(1)	1.6	0.085	1.0	0.04	4.0	0.47	1.0
Plagianthus sp.	(1)	2.5	0.22	1.2	3.1	2.2	0.73	0.82
Thryptomene maisonneuvii	(5)	0.90	0.031	0.39	0.02	1.5	0.22	0.11
Eucalyptus youngiana	(1)	0.90	0.030	0.51	0.22	0.67	0.21	0.09
E. ewartiana	(1)	0.90	0.034	0.54	0.01	1.5	0.27	0.09
E. gamophylla	(2)	1.0	0.037	0.51	0.28	1.3	0.34	0.10
E. kingsmillii	(1)	0.90	0.044	1.2	0.01	1.1	0.14	0.07
E. camaldulensis	(1)	1.3	0.089	0.85	0.03	0.90	0.43	0.12
E. sp.	(2)	0.85	0.047	0.56	0.01	0.59	0.28	0.11
Dicrastylis sp.	(3)	1.3	0.055	0.57	0.01	0.95	0.33	0.15
Lycium australe	(2)	2.3	0.16	1.9	0.4	2.9	1.6	0.55
Solanum lasiophyllum	(2)	2.6	0.14	2.0	0.02	1.1	0.31	0.23
Eremophila latrobei	(5)	2.3	0.10	2.2	0.02	1.2	0.33	0.20
E. cuneifolia	(2)	1.2	0.051	2.2	0.02	1.5	0.19	0.16
E. leucophylla	(2)	2.0	0.12	2.4	0.01	1.0	0.29	0.24
E. longifolia	(1)	1.5	0.14	1.9	0.01	0.62	0.17	0.13
E. foliosissima	(1)	2.3	0.12	2.3	0.01	0.82	0.18	0.17
E. pterocarpa	(2)	2.5	0.24	1.4	1.6	1.4	0.18	0.85
E. fraseri	(1)	2.0	0.14	1.4	0.05	1.5	0.37	0.22
E. sp.	(2)	1.3	0.050	1.3	0.02	0.81	0.27	0.14
Canthium latifolium	(2)	1.5	0.041	0.65	0.02	1.6	0.15	0.83
Scaevola spinescens	(1)	2.0	0.070	2.4	0.01	0.90	0.38	0.22
Helipterum adpressum	(1)	1.2	0.060	0.87	0.01	0.81	0.16	0.11
Cephalipterum sp.	(1)	2.8	0.14	2.7	0.02	1.9	0.34	0.19
* *A. inflata* (New South Wales) (Beadle, Whalley and Gibson 1957)		2.7	0.18	1.5	7.4	0.56		

Figure 5.—Mulga (*Acacia aneura* and spp) occurs on broad plains, particularly in the western half of the area inspected.

Figure 6.—Spinifex (*Triodia* spp) occurs on gravelly uplands, together with scattered trees of *Acacia*, *Hakea* and *Eucalyptus*.

Figure 7.—Dune vegetation is of scattered trees of *Acacia* spp with a low shrub cover of *Thryptomene maisonneuvii* and extensive spinifex (*Triodia* spp).

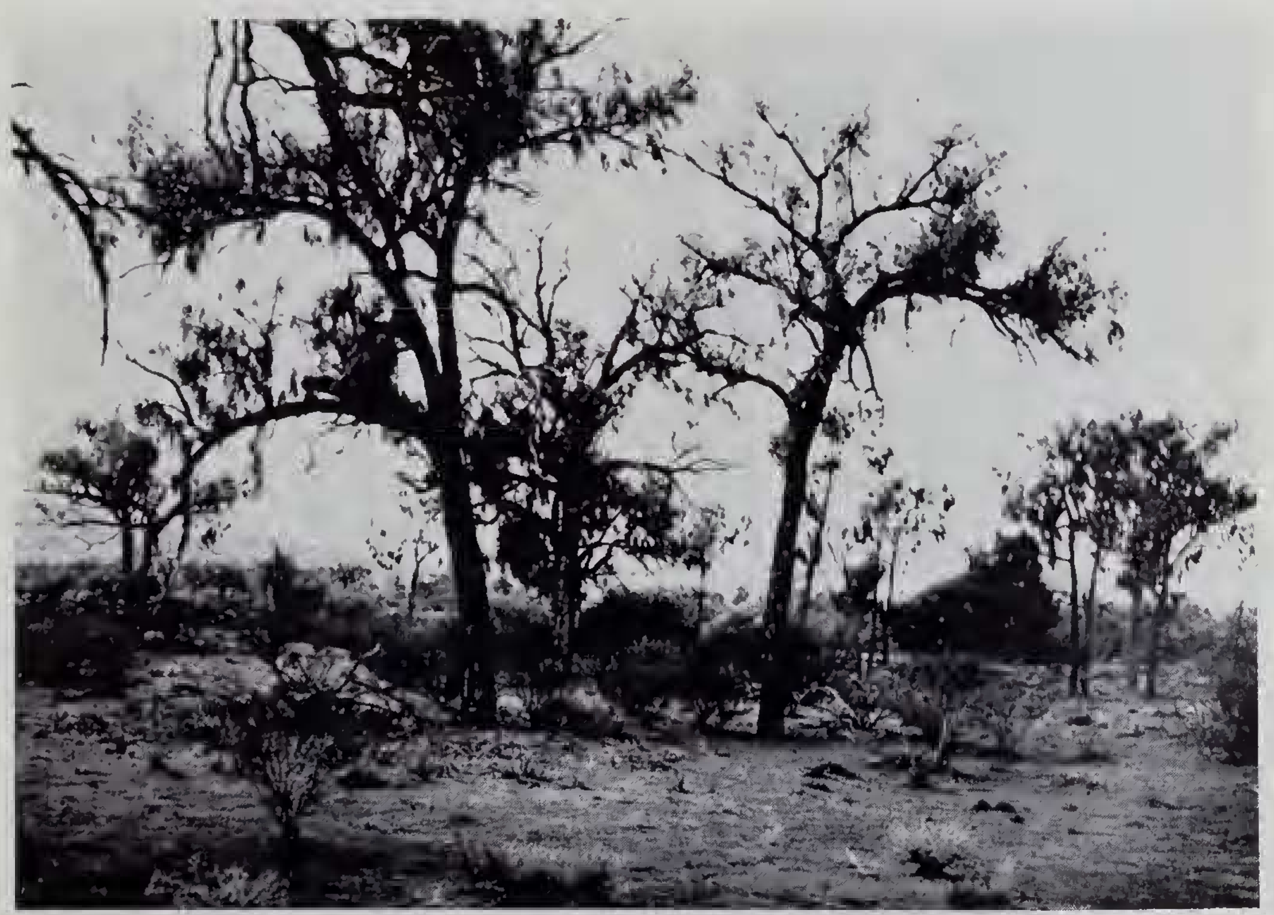

Figure 8.—Desert oak (*Casuarina decaisneana*) occurs on restricted flats, particularly near some of the less saline drainage lines.

the same sites have no accumulation of calcium sulphate on their foliage. The deposition of gypsum on the outer surface of the leaf could be explained by the evaporation of a leaf exudate, but the reason for the specific composition is not evident.

Several other species have high concentrations of sulphur; *Hakea arida*, *Hemichroa diandra*, *Gyrostemon ramulosus*, and *Alyogyne pinonianus* all have 1% or more sulphur in the dried foliage. These species also have relatively high concentrations of calcium, but since only a single specimen of each was collected, the entire sample was ground prior to analysis, and the same microscopic examination was not possible. The foliage samples could not be standardised by age or position, and consequently the high variability can be expected to allow only gross differences between species to appear. The effect of age would be particularly pronounced on the potassium and calcium concentrations, but would also occur on the other elements. Where single specimens were collected a high calcium content could be a reflection of a predominance of old tissue in the sample.

The concentrations of sodium, potassium, calcium, and magnesium, in m.equiv./g dry-weight, for all samples of *Atriplex*, *Salsola*, *Kochia*, and *Bassia* is given in Table 8. The sums of the four cationic concentrations vary by

TABLE 8

The concentrations (m. equiv./g dry-weight) of cations in some halophytes

	K	Na	Ca	Mg	*Sum*
Atriplex hymenotheca ..	0·73	3·07	0·73	0·65	5·18
A. inflata ...	0·83	2·59	0·68	1·75	5·85
Kochia pyramidata	0·64	3·77	0·50	0·63	5·54
K. carnosa	0·62	2·38	0·30	1·00	4·30
K. sp. ..	0·77	4·77	0·41	0·48	6·43
Salsola kali	2·28	0·78	1·12	0·98	5·16
Bassia drummondii	0·39	3·09	0·58	0·30	4·36
B. gardneri	0·52	3·87	0·78	0·32	6·49
B. paradoxa	0·57	1·07	0·44	0·30	2·98
B. obliquicuspis ...	0·63	1·05	0·73	0·38	2·79
B. sp.	0·50	2·44	0·71	0·28	3·93

only a factor of two, while the concentrations of sodium and potassium vary by a factor of about six. Within the first three genera the total concentrations of cations cover an even narrower range. The values for *Atriplex inflata* may be compared with values reported by Osmond (1966) for the same species grown in the field. He found calcium and magnesium concentrates of 0.68 and 1.47 m.equiv/g dry-weight respectively compared with 0.68 and 1.75 m.equiv./g dry-weight in the present samples. Analytical data were also reported by Beadle, Whalley, and Gibson (1957) for a range of *Atriplex* species, and for two samples of *A. inflata* they found the concentrations given in the footnote to Table 7. The concentrations found in the three different regions were similar.

Among the halophytes *Salsola kali* and *Rhagodia gaudichaudiana* are distinguished from the others in having very high concentrations of potassium and relatively low concentrations of sodium. The other chenopods have a high concentration of sodium and a relatively low concentration of potassium. The strong specificity for potassium uptake in these two species presumably arises in the roots, and implies a highly selective mechanism for the exclusion of sodium, which is not shared to the same degree by the other halophytes examined. All plants are able to concentrate potassium against a concentration gradient between the cell contents and the soil solution, but the concentrations in the dry-matter of *Salsola kali* and *Rhagodia gaudichaudiana* are unusually high.

Osmond (1966) examined the uptake of cations by *Atriplex* and suggested that the two processes could be involved, a 'specific' process involving cell metabolism and a 'luxury' process, possibly independent of metabolism, which operated at high concentrations of the nutrient solution. While such a passive process may account adequately for the cationic composition of most halophytes, the different ratios of potassium to sodium found between *Salsola kali* and *Rhogodia gaudichaudiana* and the other halophytes growing in close proximity suggests that specificity may extend into the higher concentration ranges for these species.

The single specimen of *Calandrina balonensis* also has a high concentration of potassium although growing in a non-saline environment.

Acknowledgements

The authors are grateful to Dr. G. A. Dean and Mr. M. A. Chapman for assistance wilth the chemical analyses. Mr. R. D. Royce of the Western Australian Department of Agriculture kindly identified plant specimens.

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